Developmental Cognitive Neuroscience 2S (2012) S114–S128

Contents lists available at SciVerse ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Differences in neural activation between preterm and full term born adolescents on a sentence comprehension task: Implications for educational accommodations

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ARTICLE INFO

Article history:
Received 8 June 2011
Received in revised form 19 October 2011
Accepted 20 October 2011

Keywords:
Language
Comprehension
Prematurity
Preterm
fMRI
Education

ABSTRACT

Adolescent survivors of preterm birth experience persistent functional problems that negatively impact academic outcomes, even when standardized measures of cognition and language suggest normal ability. In this fMRI study, we compared the neural activation supporting auditory sentence comprehension in two groups of adolescents (ages 9–16 years); sentences varied in length and syntactic difficulty. Preterms ($n = 18$, mean gestational age 28.8 weeks) and full terms ($n = 14$) had scores on verbal IQ, receptive vocabulary, and receptive language tests that were within or above normal limits and similar between groups. In early and late phases of the trial, we found interactions by group and length; in the late phase, we also found a group by syntactic difficulty interaction. *Post hoc* tests revealed that preterms demonstrated significant activation in the left and right middle frontal gyri as syntactic difficulty increased. ANCOVA showed that the interactions could not be attributed to differences in age, receptive language skill, or reaction time. Results are consistent with the hypothesis that preterm birth modulates brain–behavior relations in sentence comprehension as task demands increase. We suggest preterms' differences in neural processing may indicate a need for educational accommodations, even when formal test scores indicate normal academic achievement.

1. Introduction

We have long known that extrinsic and intrinsic factors contribute to individual differences in educational achievement. Extrinsic factors include socioeconomic status (Hackman et al., 2010; Kishiyama et al., 2009), size and quality of support systems (Somers et al., 2008), and teacher effectiveness (Stronge et al., 2007). Intrinsic factors include sex (Buchmann et al., 2008; Kraft and Nickel, 1995), motivation (Duckworth et al., 2011; Li-Grining et al., 2010), and intelligence (Deary et al., 2007; Sternberg et al., 2001).

We have only recently begun to learn via neuroscience research that even when academic ability is *equated*, extrinsic or intrinsic factors modulate where cognitive information is processed in the brain. For example, Noble et al. (2006) obtained functional magnetic resonance imaging (fMRI) on children from diverse socioeconomic backgrounds (SES) and with equivalent below average phonological skill. They found the children in the lower SES group showed a positive correlation between phonological awareness and activity in the left fusiform gyrus, but children from the higher SES group did not show this correlation. The area of difference is one that is particularly

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doi:10.1016/j.dcn.2011.10.002

responsive to visually presented words relative to other types of visual or verbal stimuli. Thus, socioeconomic background factors were found to modulate brain–behavior relationships in reading skills. As another example, Burman et al. (2008) obtained fMRI on both sexes with high verbal skills during two linguistic tasks, using visual and auditory word presentations. After accounting for differences in accuracy, bilateral activation in the inferior frontal and superior temporal gyri and activation in the left fusiform gyrus was greater in girls than in boys. Activation in the left inferior frontal and fusiform areas of girls was also correlated with linguistic accuracy regardless of stimulus modality, whereas correlation with performance accuracy in boys was found in distinct brain areas when words were presented in the visual or auditory modality. Thus, sex was also found to modulate brain–behavior relationships in language and reading skills. Studies such as these may inform education insofar as effective education may need to tailor teaching strategies, adjust testing methods, or provide other accommodations based on characteristics of the child to improve their level of achievement or performance.

We propose that another important source of intrinsic variation, relevant to academic achievement, is the child's medical history. In this study, we focused on premature birth as an example of a pertinent aspect of a child's medical history because the condition remains prevalent in the U.S. and has long-lasting effects on language and cognitive outcomes. The specific aims of this fMRI study were to (1) compare patterns of neural activation related to auditory language comprehension in preterm and full term born adolescents, particularly when task demands increase, (2) determine if differences in the patterns of activation covary with individual differences in age, offline receptive language skill, or performance on the task, and (3) discuss the implications for educational policy and accommodations for school-age children born prematurely.

1.1. Prematurity and long term cognitive outcomes

Prematurity is a condition of utmost public health importance. A normal gestation lasts 40 weeks; each year, over 500,000 children in the U.S. are born before 37 weeks gestation, qualifying as preterm. The health and functional consequences for these children persist far beyond the newborn period. Approximately 20% of survivors born before 32 weeks gestation have a major disability, including sensory and motor impairments and severe developmental delays heralding intellectual disability (Marlow, 2004; Vohr et al., 2000). More importantly, fully 50% of all preterm children have mild to moderate disabilities that are highly pertinent to education.

These mild to moderate disabilities include cognitive, linguistic, and socio-emotional problems that persist into adulthood (Hack, 2009; Lee et al., 2010; Saigal and Doyle, 2008; Saigal and Rosenbaum, 2007). Mean IQ scores of children born preterm can be up to 20 points below those of full term controls matched for sex, SES, and race/ethnicity, even though many survivors score within the normal range (Aylward, 2002; Bhutta et al., 2002; Hack et al., 2002; Marlow, 2004). Prematurity also contributes significantly to the variance in scores on language and reading measures after controlling for sex, SES, and IQ (Lee et al., 2010). Particularly relevant to the aims of this paper is the finding that degree of prematurity has shown to be a direct predictor of linguistic processing speed for syntactic comprehension, verbal memory, and reading comprehension (Lee et al., 2010). Other outcomes of prematurity associated with poor educational achievement include weaknesses in executive function skills and high rates of inattention and anxiety symptoms (Aarnoudse-Moens et al., 2009; Aylward, 2002; Loe et al., 2011). Extremely preterm children use special education services at a much higher rate than full term children (Johnson et al., 2009), and while "late preterm" children born between 32 and 36 weeks gestation tend to use less special education services than extremely preterm children, even they experience more grade retention than full term peers. However, even preterm children whose IQ and related test scores are in the normal range and are in mainstream classrooms demonstrate lower academic achievement relative to full term peers (Ross et al., 1991).

Adverse outcomes after prematurity have been attributed to neural injuries associated with hypoxia, ischemia, and inflammation. Neuroimaging studies find reduced brain volumes following preterm birth (Nosarti et al., 2002; Reiss et al., 2004), and these volume changes are associated with cognitive outcomes (Reiss et al., 2004). Prematurity is also associated with a distinctive pattern of neural injury to periventricular cerebral white matter. These injuries can be assessed *in vivo* using Diffusion Tensor Imaging (Back et al., 2007; Soria-Pastor et al., 2008; Vangberg et al., 2006; Volpe, 2009). Microstructural properties of the white matter, such as fractional anisotropy, are correlated with many aspects of cognitive, language, and academic skills (Andrews et al., 2010; Feldman et al., 2010; Frye et al., 2008; Mullen et al., 2010). In addition, preterm birth begins an accumulation of early life experiences that may be distinctive from the early life experiences of children born at term. This early experience may also affect how children process information.

1.1.1. Functional imaging in children born preterm

Relatively few studies have used fMRI to understand neural processing in children born preterm. Peterson (2003) compared 8-year old preterm and full term participants in a passive language listening task and found that the preterm group activated areas of the brain during meaningful speech that the term children activated during phonologically elemental sounds. The findings were most pronounced among the children with the lowest verbal IQ. Ment et al. (2006) found similar results in 12-year-old children born preterm and full term. Gozzo et al. (2009) reported that functional connectivity in the language network was abnormal in children born preterm; they had stronger connections between Wernicke's area and the right inferior frontal gyrus, and between bilateral superior marginal gyri than did the full term controls. The performance of preterms on the language batteries in these studies was below that of the controls, leaving open the possibility that the results were due to language function rather than prematurity. What is needed is a study where patterns of brain activation are assessed in preterm and